Studies of Sea Surface Thermal Emission with the Small Slope Approximation

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LONG-TERM GOALS

The long term goals of this project involve developing improved understanding of sea surface thermal emission through the development and application of both analytical and numerical methods for electromagnetics and hydrodynamics. New insights regarding these phenomena can then be applied to improve microwave passive remote sensing of the ocean surface. Improving the efficiency of currently applied analytical models is also a project goal, so that use of these models in retrieval algorithms becomes more practical.

OBJECTIVES

NRL's WindSAT, launched January 2003, is the first polarimetric microwave radiometer ever in orbit. Using WindSAT measured brightness temperatures to retrieve sea surface wind speed and direction requires an understanding of the relationship between sea surface emitted microwave power and sea conditions. Analytical theories have been developed for the prediction of microwave sea surface brightness temperatures and have shown some success, but differences among the theories proposed and the limited amount of current data still makes the underlying physics unclear. Project efforts in emission theory are focused on studies and extension of the analytical models to provide improved understanding of the phenomena producing emission signatures. Development of efficient models for emission predictions is also an objective, and a web-site (esl.eng.ohio-state.edu/~rstheory/windsat.html) has been created to serve as a central location for the sea emission modeling community.

Proper modeling of the sea surface is also an issue for the development of accurate theories of sea emission. Another project objective involves the use of numerical models for sea surface hydrodynamics in order to improve understanding of the influence of non-linear hydrodynamics on emission signatures.

APPROACH

Analytical model studies of sea surface emission are focusing on the small-slope theory [1]-[5]. An extensive debate in the community is currently taking place with regard to the source of azimuthal harmonic variations of ocean brightness temperatures, particularly the relative influence of large and small scale wave structures. Uncertainties in the ocean surface directional spectrum and in long-short wave hydrodynamic modulations make this a difficult question to resolve conclusively, but studies of

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14. ABSTRACT
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emission theories can reveal the extent to which asymmetry in differing length scales can contribute to observed harmonics independent of the directional spectrum model used. The vast amount of WindSAT data currently being obtained will also help to resolve these issues through comparisons of models and measurements when ground truth information is available (the “cal-val” process). The small-slope theory of sea emission is similar in many respects to the widely-used (but less rigorous) “two-scale” theory, so comparison and evaluation of these two models is a central project goal. Efforts to improve the overall efficiency of both the small slope and two-scale codes are also in progress.

The numerical models of hydrodynamic evolution (for both two and three dimensional rough sea surfaces) used are based on [6]-[7]. Although these numerical models are computationally expensive for large-scale surfaces, and can experience stability problems, the non-linear features captured by these models are not easily reproduced by any other means. With regard to sea surface emission, a particular issue is the modulation of the short wave spectrum along the surface of longer waves, which contributes to the up/down wind asymmetry of surface brightness temperatures. Although linear theories of this process are available, they are generally known to be inaccurate and to underestimate the degree of modulation obtained. The hydrodynamic codes developed for the project are being used to study this effect so that better models of the long-short wave modulation can be included in sea emission predictions.

WORK COMPLETED

Several new developments have occurred in FY 03. The analytical expressions for a fourth order small slope theory of sea surface emission developed in FY02 [5] have been simplified to make their use more practical. A by-product of these efforts is a convenient recursive form for computation of arbitrary-order surface scattering coefficients under the small perturbation method [8]; these results can find application in a variety of areas outside the emission modeling studies considered here. Efforts begun in FY02 to compute long-short wave interaction effects efficiently continue; difficulties found in several near-singular integration regions have now been resolved. Once evaluated these results will provide the first appropriate assessment of “tilting” effects computed in the two-scale model.

To facilitate comparisons with the two-scale theory, a highly efficient two-scale model implementation has been developed [9]. The four-fold integration implicit in the two-scale model has been effectively reduced to a three-fold integration through the use of a separate table of emission “weighting functions”. In addition, emission results at multiple azimuthal observation angles are computed in the new implementation without extensive repeat calculations. The resulting code achieves approximately a 100 fold improvement in CPU time compared to a two-scale implementation previously used by the NRL WindSAT team. The new implementation has been delivered to the NRL WindSAT team and is being used in the wind-vector retrieval process.

Reflected atmospheric emissions also play a role in producing sea emission signatures, and must be captured by a realistic model. Recent project efforts have developed a highly efficient two-scale implementation that includes computation of the reflected atmospheric brightness. Studies of the results of this code are currently in progress, and will be reported to the NRL WindSAT team.

Finally, the sea emission modeling web page has been continually maintained to provide a location for comparisons of model implementations by members of the sea emission modeling community.

RESULTS

Figure 1 compares predicted zeroth, first, and second azimuthal harmonics of sea brightnesses versus windspeed at 19.35 GHz and observation angle 55 degrees. Results were generated using the small slope theory (dashed curves), the previous NRL two-scale model implementation (solid curves), and an empirical model produced from data measured by the Jet Propulsion Laboratory (symbols). Predictions were generated using the "Durden-Vesecky" model of the sea spectrum [10], although the NRL model includes some modifications to this spectrum [9]. The multiple colors in each plot refer to the four polarizations measured by a polarimetric radiometer. Results show both models to match the empirical data relatively well, although some significant differences are observed. Both models overestimate second harmonics at high wind-speeds; this likely is due to limitations of the sea spectrum model used. The SSA model is observed to provide a somewhat improved match to the empirical first-harmonic results, particularly in horizontal polarization. Zeroth azimuthal harmonics are different by up to 4-5K between the two models, which can have an important impact on wind speed estimation.

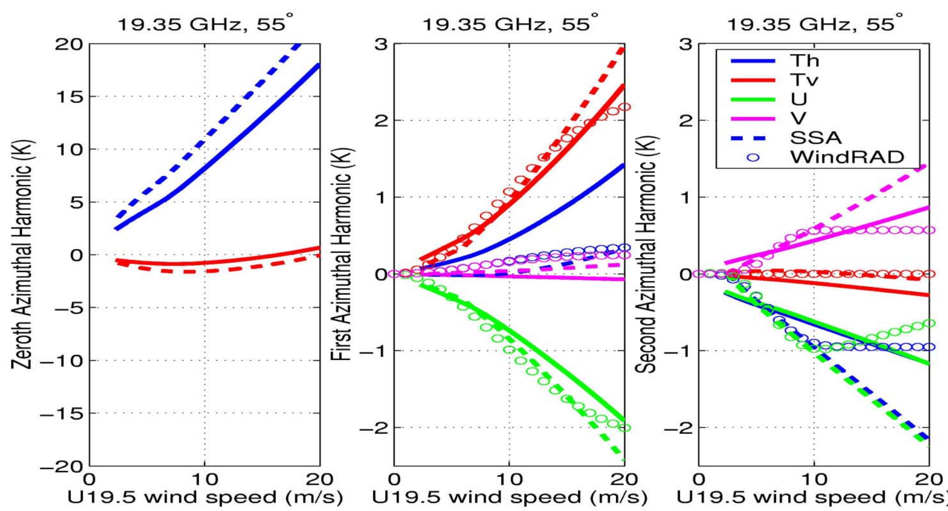

Figure 1: Comparison of the small slope and two-scale theories for emission from a "Durden-Vesecky" sea surface. Solid curves are from the NRL two-scale model, dashed curves from the small-slope theory, symbols from the JPL WindRAD empirical model

Figure 2 illustrates similar results comparing the previous NRL two-scale model implementation (solid) with the original two-scale model of Yueh (dashed) [10]. The distinction between these two computations lies only in the modifications made to the spectrum by NRL. Again reasonable agreement with the empirical data is observed in both cases, although the Yueh implementation shows larger zeroth harmonics and somewhat larger second harmonics. At present, there is insufficient data to conclusively establish one emission theory or sea spectrum model over another; data from WindSAT will change this situation, and will be incorporated into project studies as it is made available.

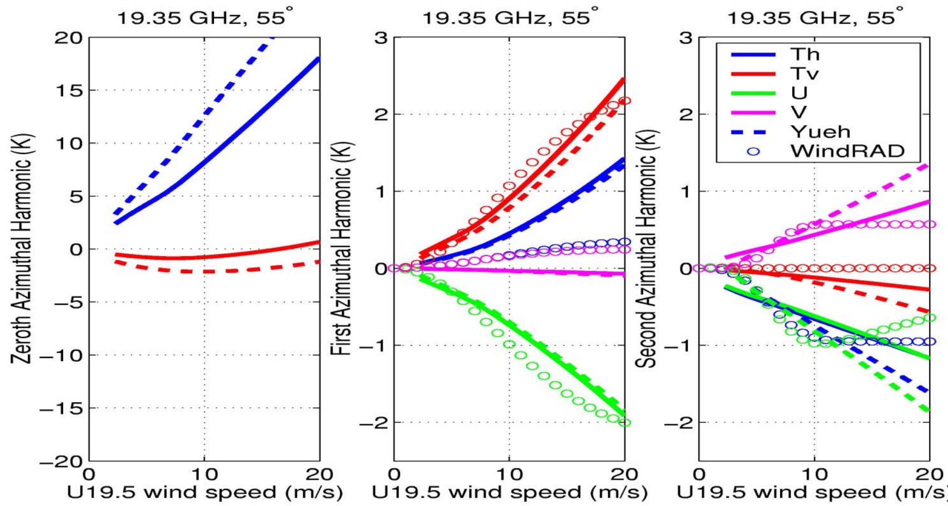

Figure 2: Results from the two-scale theory for emission from a "Durden-Vesecky" sea surface. Solid curves are from the NRL two-scale model, dashed curves from the two-scale model of Yueh, symbols from the JPL WindRAD empirical model

IMPACT/APPLICATIONS

Project results immediately impact methods for passive remote sensing of ocean wind vectors, in particular for WindSAT retrievals but also for design and application of sensors in the NPOESS generation of satellites. The improved surface-scattering theories implicit in the emission models are also applicable to active sea sensing problems, as well as general rough surface scattering studies. New insights into sea surface scattering will allow improved clutter reduction and active sea surface sensing methods to be created. The hydrodynamic portions of the project influence both active and passive sea remote sensing, as well as other oceanographic disciplines.

TRANSITIONS

The efficient two-scale model implementation discussed has been delivered to the NRL WindSAT team and is being applied in wind-vector retrievals. Transition of the atmospheric reflection code is in progress. Project results regarding the accuracy of varying sea emission models will also be communicated to the WindSAT team, as well as the wider passive sensing community.

RELATED PROJECTS

Current related projects include:

1. an NSF sponsored project with Prof. Greg Baker (Math dept.) on development of hydrodynamic models for wind forcing of the sea surface

2. an NRL/NPOESS project on application of existing emission models to analysis of WindSAT data (began 8/03)

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5 conference publications in 2003

HONORS/AWARDS

J. T. Johnson, 2002 Booker Fellowship, U.S. National Committee of International Union of Radio Science (“the pre-eminent triennial award to a young US radio scientist.”)

J. T. Johnson, 2003 OSU College of Engineering Lumley Research Award